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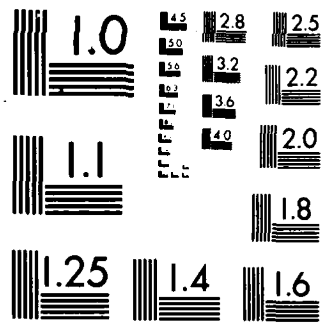

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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USAFETAC/TN-86/002

OPTIMUM PERIOD OF RECORD

By

RONALD RODNEY

USAFETAC/OL-A

Asheville, North Carolina

JULY 1986

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19. Abstract: Percentage frequency of occurrence of ceilings and visibilities, as well as monthly means of temperature, precipitation, and pressure, were examined for their relative representative application to current climatology. Several U.S. and overseas locations showed climatological changes that rendered normals ineffective as tools for describing or predicting current weather conditions. Monthly values were compared to running means for 1 through 31 antecedent years. The mean closest to the actual value was tallied as the "best." This scoring system was applied to periods of record beginning as early as the 1700's, and usually showed that shorter means of 1 to 7 years were frequently closest to actual values.

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PREFACE

This technical note was prepared by the United States Air Force Environmental Technical Applications Center's Operating Location A (OL-A) at Asheville, North Carolina. The author wishes to thank Mrs D. Norton and Ms P. Wicker for their work in converting handwritten notes to typed copy. Special thanks also to programmers J. Crouch, V. Liles, and D. Smith.

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INTRODUCTION

1.1 Purpose of the Study. Although Department of Defense (DoD) agencies around the world are demanding more climatic information than ever before, most military climatology requirements call for just one element: An *arithmetic mean.* For example, most DoD planners need *means* of temperature, precipitation, wind speed, pressure, relative humidity, etc., stratified by month. An "optimum period of record"--the ideal size of the climatological database upon which these means are computed--has always been at question by climatologists. Studies of that question, including some very recent ones, have shown that use of a very long period of record (or POR) is not only a waste of manpower and computer time, but may even result in the provision of misleading climatological information. It therefore seems clear that *more,* in terms of size of the climatological database, does not necessarily mean *better.* The purpose of this study, performed by Operating Location A of the USAF Environmental Technical Applications Center, is to examine the evidence and offer recommendations for an optimum period of record to be used in determining monthly climatic data.

1.2 Stability of the Mean. Meteorologists have been looking for the minimum number of years required to arrive at a stable mean since 1943. In their quest for an answer, they have generally concluded that if the addition of one more year of data changed a monthly mean, the original period of record was too short. On the other hand, if there was no significant change, the original number of years was looked upon as "optimum." Landsberg and Jacobs (AMS 1951) summarized the results of some very early studies with this table:

TABLE 1. Approximate Number of Years Needed to Obtain a Stable Frequency Distribution (After Landsberg and Jacobs, 1951.

EXTRATROPICAL REGIONS	Islands	Shore	Plains	Mountains
Temperature	10	15	15	25
Humidity	3	6	5	10
Cloudiness	4	4	8	12
Visibility	5	5	5	8
Precipitation amount	25	30	40	50
TROPICAL REGIONS	**Islands**	**Shore**	**Plains**	**Mountains**
Temperature	5	8	10	15
Humidity	1	2	3	6
Cloudiness	2	4	4	6
Visibility	3	3	4	6
Precipitation amounts	30	40	40	50

One of the early papers used by Landsberg and Jacobs was AWS Technical Report 105-25, *Study of Length of Record Needed to Obtain Satisfactory Climatic Summaries for Various Meteorological Elements,* November 1943. The stated purpose of that report was "to establish the number of years required to obtain a relatively constant frequency distribution of various meteorological elements." Using manual tabulation, this early Army Air Force study addressed only those elements "which had not been studied previously." Using an extremely limited database, these AWS pioneers concluded that the

minimum number of years required for monthly frequency distributions varied by geographic location. The "optimum period of record" they derived is shown in Table 2.

TABLE 2. Number of Years Required for Stability of the Frequency Distribution (After Landsberg and Jacobs, 1943).

	Westerly Circulation	Subtropical Circulation
Visibility	7	10
Cloud Height	6	7
Cloudiness	11	Insufficient data
Wind velocity	7	9
Precipitation		
Persistence on successive days	20	Insufficient data

1.1 **What Does "Normal" Mean?** The American Meteorological Society (AMS) *Glossary of Meteorology* gives three definitions for "normal" as it applies in this study. The following abbreviated forms of those definitions may help the reader appreciate the real meaning of this frequently overworked word.

Normal As in a *normal* distribution.

Normal Typical in the sense of lying within the limits of common occurrence, but sometimes denoting a unique value as a measure of central tendency.

Normal The average value of a meteorological element over any fixed period of years that is recognized as *standard*. Internationally, the fixed number of years is set at 30, with normals recalculated at the end of each decade.

Landsberg's *Weather "Normals" and Normal Weather* (Environmental Data Service, 1972) provides a history of this word and its elusive meaning(s). It appears to have arisen from an early meteorologist's search for a universal standard to use for comparison purposes. The quest for such a standard goes on, as meteorologists of today continue to seek the equally elusive "optimum period of record."

1.4 **Standard Error Estimates of the Optimum Length of Record.** If the climate is assumed to be invariant, with only random variations from year to year (as it was assumed to be during the early part of this century), the formula for a standard deviation of the normal is actually the standard error of a mean. As pointed out by Court (1967), a 100-year mean is thus twice as precise as a 25-year mean as an estimate of the "true" mean. Using the following formula and calculated standard deviations, many investigators have solved for *k*, or the number of independent years required to attain some desired precision, say $S_{\bar{x}} = 1$ °F.

$$S_{\bar{x}} = \frac{\delta}{\sqrt{k}}$$

Where: $S_{\bar{x}}$ = standard error of mean,

δ = standard deviation of observations, and

k = number of independent observations.

1.5. Estimates of the Standard Deviation Increase with Length of Record. Court (1967) found that "fluctuations in short-period means cause estimates of the standard deviation of a climatic element to increase with the length of the record." Similar increases in estimates of the standard deviation are caused by inhomogeneities in the observations. In addition to the basic assumption of the above equation, random sampling of statistically independent observations may not be valid in the strictest sense.

1.6 Representative Monthly Rainfall Statistics. The literature is replete with articles on the best or optimum statistic for monthly rainfall data. After 50 years of controversy over the use of mean versus median, the consensus shows the *median* to be most representative of monthly rainfall ano therefore the preferred statistic. Meisner (1979) and Landsberg (1951) found median monthly rainfall values to stabilize before mean monthly values. The optimum period of record for rainfall data medians, therefore, is shorter than the optimum period of record for means. Despite the median's advantages, the mean continues to be computed because of its wide use as a distribution factor.

1.7 Minimum Length of Record Using Confidence Limits. Lenhard and Baum (1954) assumed random sampling from a basically normal population and calculated the "minimum record required to obtain" January and July normals of specified reliability for seven stations. They found that *fewer years were required for July than for January to achieve the same reliability.*and noted that, generally, the "July standard deviation of normal temperatures were *(sic)* found to be about one-half as large as January values." The data also shows some indication of geographical influence, with decreasing reliability at more northerly sites and with some degree of continentality.

Chapter 2

MEANS AS PREDICTORS

2.1 Classical Descriptive Statistics vs. an Empirical Approach. The literature of climatology documents two approaches to solving environmental problems. First, there is the classical descriptive statistical method centered on normality means, standard deviations, standard errors, frequency distributions, and stability of elements. There is also the more pragmatic approach, which, simply put, says that if something works, use it. Although early climatologists favored descriptive statistics, many current investigators are looking for values that can be used to predict the future. Air Weather Service, for example, has sanctioned a number of studies that emphasize the predictive value of climatic statistics.

2.2 Past Weather--Our Future. We implicitly assume that the future will resemble the past. The major value in collecting historical weather information and calculating various climatological statistics is that all such information helps describe the future. The USAF Environmental Technical Applications Center, whose motto is "Past Weather--Our Future," provides climatic summaries used throughout the Department of Defense. These summaries help predict future weather and climatic conditions that can affect military operations, people, and equipment.

2.3 "Courting" a New Philosophy of Climatic Averages. Court (1967,1968) was one of the first climatologists to explicitly advocate the predictive value of averages and to evaluate how well they perform as predictors. In his final report on "Climatic Normals as Predictors" (1968), Court comments on the situation as he saw it:

> In summarizing their statistics..., few climatologists consider the uses to which the results will be put. They follow faithfully the 19th century criteria for characterising climate, although granting grudgingly the fallacy of the concomitant concept of climatic constancy. Climatology is far more persistent than is climate.
>
> Climatic "normals," cornerstones of climatology, are senescent survivors of the pervasive proposition of permanency. Until the last century, hills were everlasting, biologic species had not changed since Creation, and "climate" was the fixed value about which weather conditions varied randomly. The accepted characteristics of a species were averages of many measurements of individual eagles or eels or elephants, and the "true" climate was the average of weather observations for many years, the more the better.
>
> With the slow acceptance, in this century, of the reality of climatic changes and fluctuations, the 19th century description of a place's climate by the average of all available observations, regardless of when made, has been replaced by a rigid recipe: the mean of observations during a period of 30 consecutive years, beginning in 1901, 1931, 1961, etc...

Court continues, explaining that while a 30-year mean is stable, "The presumed precision of a climatic quantity...has much less intrinsic importance than the expected error with which it forecasts future phenomena." With that, he sets out to find what period of record should be used to "approximate most closely coming conditions."

Chapter 3

THE SEARCH FOR AN OPTIMUM PERIOD OF RECORD

3.1 World Monthly Surface Station Climatology. The World Monthly Surface Station Climatology Data Set maintained by the National Center for Atmospheric Research (NCAR) and the National Climatic Data Center (NCDC) was used for much of the work that went into this report. This quality-controlled data set gives monthly means and amounts for more than 2,500 stations worldwide; some records go back 200 years. The major elements are precipitation, temperature, station pressure, and sea level pressure (Spangler and Jenne 1981).

3.2 DATSAV Hourly Observations. Unfortunately, world monthly surface station climatology does not include ceiling and visibility data. Because of the military significance of those elements, OL-A generated year-month frequency of occurrence files using USAFETAC DATSAV hourly data. Although other stations were examined, OL-A concentrated on the thirteen listed below--all with extensive and continuous periods of record, and all in fairly diverse climatic regions. Although all these stations were studied, those in the CONUS received the major emphasis.

Adak, NAS, Alaska	Fairchild AFB, Washington	Minot AFB, North Dakota
Buckley ANGB, Colorado	Fort Belvoir, Virgina	RAF Upper Heyford, UK
Castle AFB, California	Grissom AFB, Indiana	Scott AFB, Illinois
Ellington AFB, Texas	Luke AFB, Arizona	Yokota AB, Japan
Eglin AFB, Florida		

3.3 Visibility Fluctuations. Figure 1 shows the variation (in percent frequency of occurrence) for December visibilities equal to or greater than each of four categories (1, 2, 3, and 5 miles) at Ellington AFB, Texas.

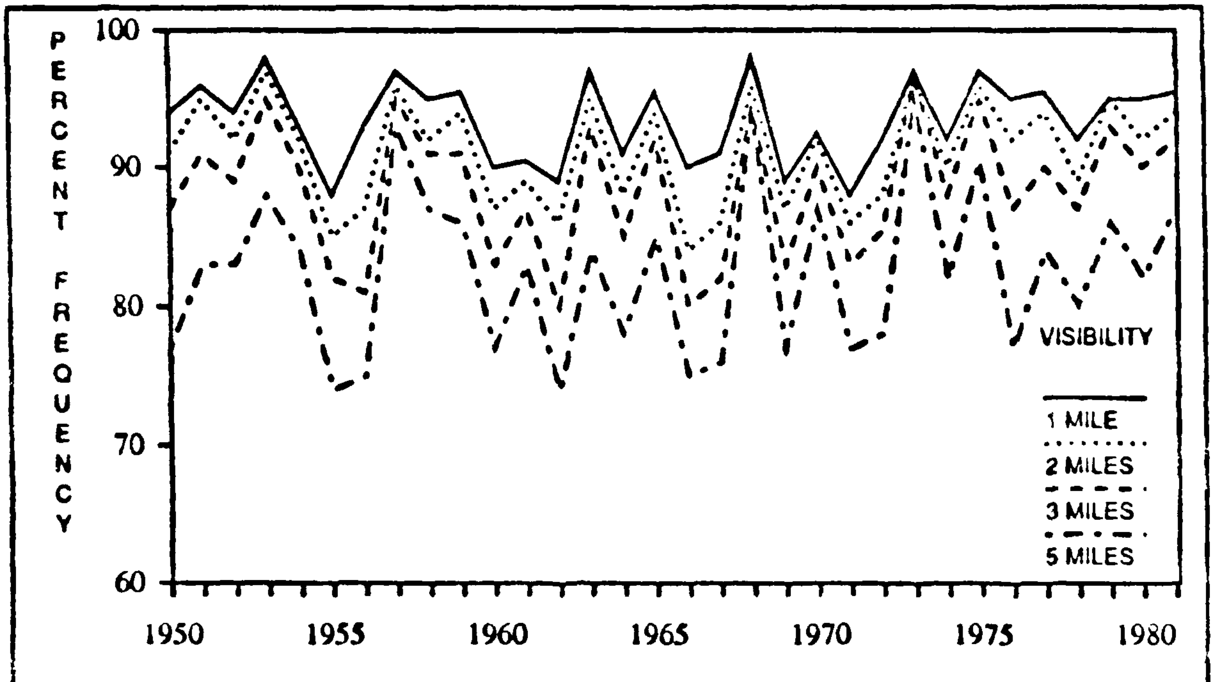

Figure 1. Frequency of Selected December Visibilities, Ellington AFB, Texas.

Note that the variation for the least restrictive category (5 miles) is as much as 19 percent in just 1 year, increasing from 75 percent in 1956 to 93 percent in 1957. Note also that the lower visibilities (such as 1/2 mile) vary "in synch" with the 5-mile variations, even though the absolute size of their flluctuations is not as large as the 5-mile changes. The graphic representations of these fluctuations appear at first to be cyclic. However, when the data was randomized and regraphed, it still appeared cyclic to casual observers. Although intrigued by cycles, OL-A did not investigate them during this study. The Ellington AFB case is just one example; OL-A actually calculated all months at all 13 stations and, as expected, some months showed little fluctuation.

3.4 Ceiling Fluctuations. Figure 2 shows percent frequency of occurrence for ceilings equal to or greater than each of four categories (1,000, 1,500, 3,000, and 5,000 feet) for Ellington AFB, Texas. Note that the fluctuation pattern is similar to that for visibility. Although low ceilings and visibilities were expected to occur concurrently, the magnitude of the monthly fluctuations was surprising.

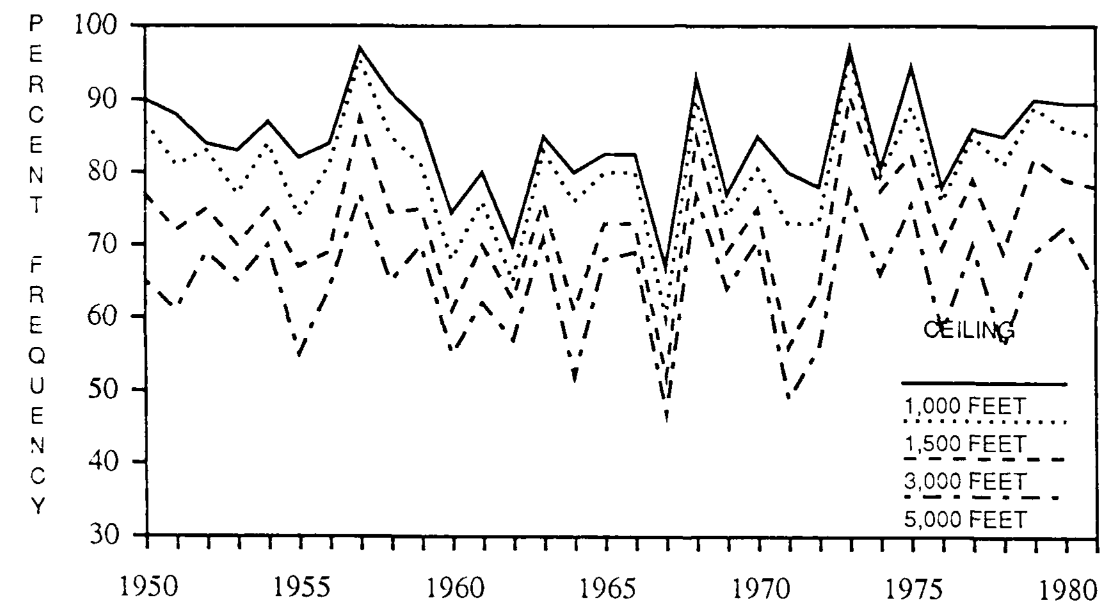

Figure 2. Frequency of Selected December Ceilings, Ellington AFB, Texas.

3.5 Rare Events Excluded from Study. Yokota AB, Near Tokyo, is noted for its low ceilings and visibilities in July. In Figure 3, which shows frequencies of selected Yokota July ceilings, note the absence of significant year-to-year variation in ceilings greater than or equal to 200 feet. Note also that the 200-foot fluctuations, however slight, are synchronous with the other categories. But the frequency of occurrence of ceilings below 200 feet is so rare that it appears to be very stable and not necessarily synchronous with fluctuations in other categories. For these reasons, rare events and categories were

dropped from the optimum period of record study. If, however, these low ceilings and visibilities were expressed as frequency of occurrence *below* some criteria, we can see that the sizes of the changes are very large when compared to individual monthly values.

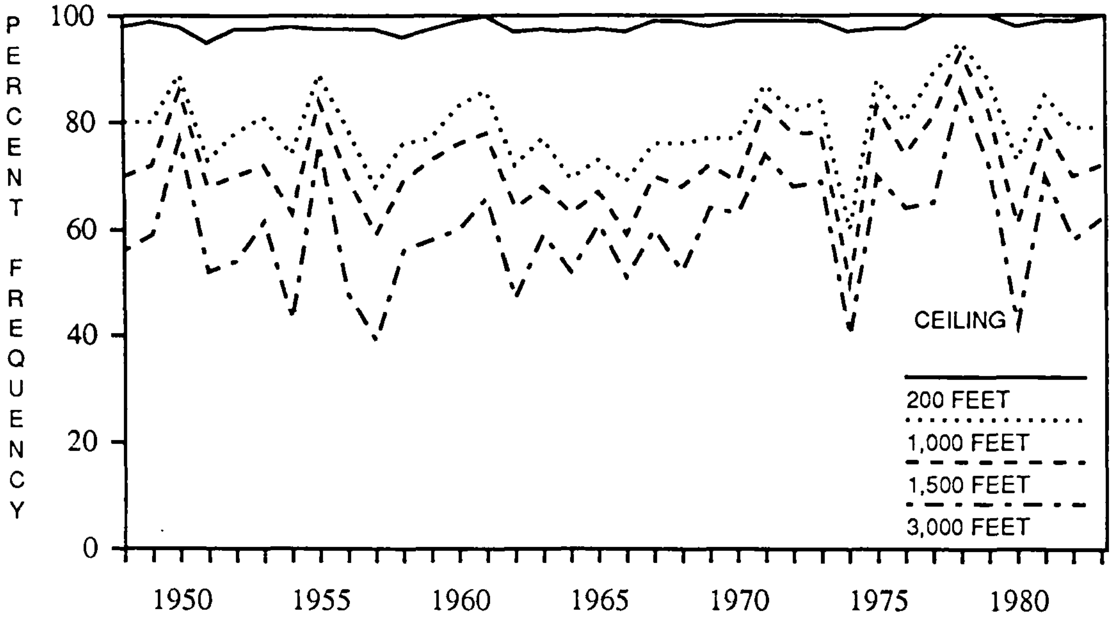

Figure 3. Frequency of Selected July Ceilings, Yokota AB, Japan.

3.6 Stable Means Not Necessarily Good Predictors. Figure 4 charts running means of 3, 11, and 31 years for January temperatures at Charleston, South Carolina. It illustrates a fundamental statistical principle: the longer the mean, the more stable the value. Chapter 2 discussed the question of how many years were required to achieve stability of a monthly value, and how long it was before meteorologists began to evaluate means according to how they performed as predictors. Actual yearly -monthly values (shown as superimposed stars) have been added to Figure 4 to show how each running mean performed as a predictor. Despite the supposed stability of the 31-year mean, we find that it fails miserably.as a predictor.

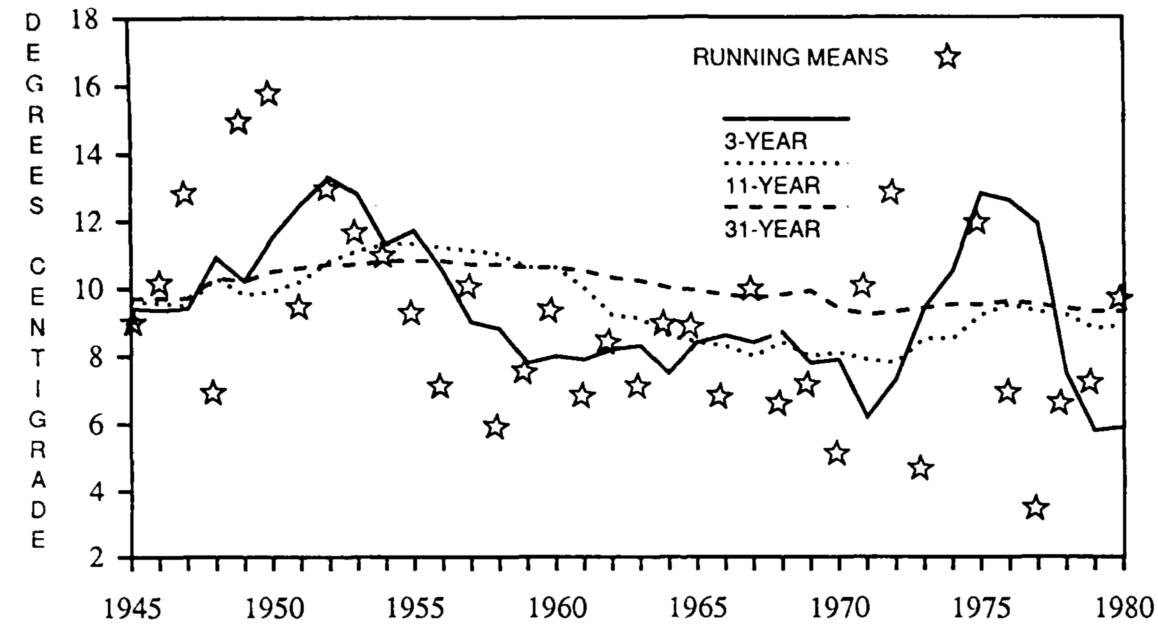

Figure 4. Running Means of January Mean Temperature, Charleston AFB, South Carolina

3.7 Running Means Using Antecedent Years. For this study, OL-A calculated some monthly running means and compared them to what happened for each of the next 5 years. For purposes of illustration, let's say our database runs from 1938 through 1982. If we used 3-year means, 1938, 1939, and 1940 would be used to predict 1941. Similarly, the last year of available data (1982) dictates that 1979 through 1981 would form the last mean, as shown in Figure 5.

$$\left.\begin{array}{l}\mathit{1938}\\ \mathit{1939}\\ \mathit{1940}\end{array}\right\}\overline{X}_3 \textit{ for 1941} \qquad \left.\begin{array}{l}\mathit{1979}\\ \mathit{1980}\\ \mathit{1981}\end{array}\right\}\overline{X}_3 \textit{ for 1982}$$

1941 1982

Figure 5. Running Means Using Antecedent Years.

3.8 Running Means Using Lag Years. There is often a time lag of several years between the last year used in the mean and the predicted year. Using the example for 1938 tthrough 1982, and assuming the same 3-year mean, it follows that for a lag of 2 years, the first available mean would be for predicting 1943. The last verification on 1982 data would use 1977 through 1979, as shown in Figure 6.

LAG 0	LAG 2
1938	*1938*
1939 $\bar{X}_3$ *for 1941*	*1939* $\bar{X}_3$ *for 1943*
1940	*1940*
1941	1941
1942	1942
... .	....
....	*1977*
....	*1978* $\bar{X}_3$ *for 1982*
1979	*1979*
1980 $\bar{X}_3$ *for 1982*	1980
1981	1981
1982	1982

Figure 6. Running Means Using Lag Years.

3.9 How Close Was the Prediction? Using running means as predictors, OL-A looked for an optimum period of record, remembering that "optimum" means different things to different people. Returning to the Charleston temperature graphs in Figure 4, we can see that one way to evaluate the predictors is to look at the error. Actually, these values, squared and summed, then divided by the number of predictions, would be one way of determining the optimum period of record. But Arnold Court (1967) calculated more than 7,000 of these extrapolation variances and concluded that it was generally a waste of time and, in some cases, detrimental, to use more than about 15 years of data.

3.10 **Theoretical Vs. Actual Temperature Variances.** Figure 7 was prepared after Court (1967). It shows how the extrapolation variance changes with increasing period of record. It also shows the theoretical variance you would expect from a standard normal distribution, as well as actual extrapolation variances of temperature for Lynchburg, Virginia. If minimum variance, then, is our criteria for optimum period of record, we can see that 10-15 years would, in most cases, be a good choice. Although OL-A did not try to reinvent the wheel or reproduce Court's work, it did calculate some extrapolation variances for various thresholds of ceiling and visibility to arrive at similar results.

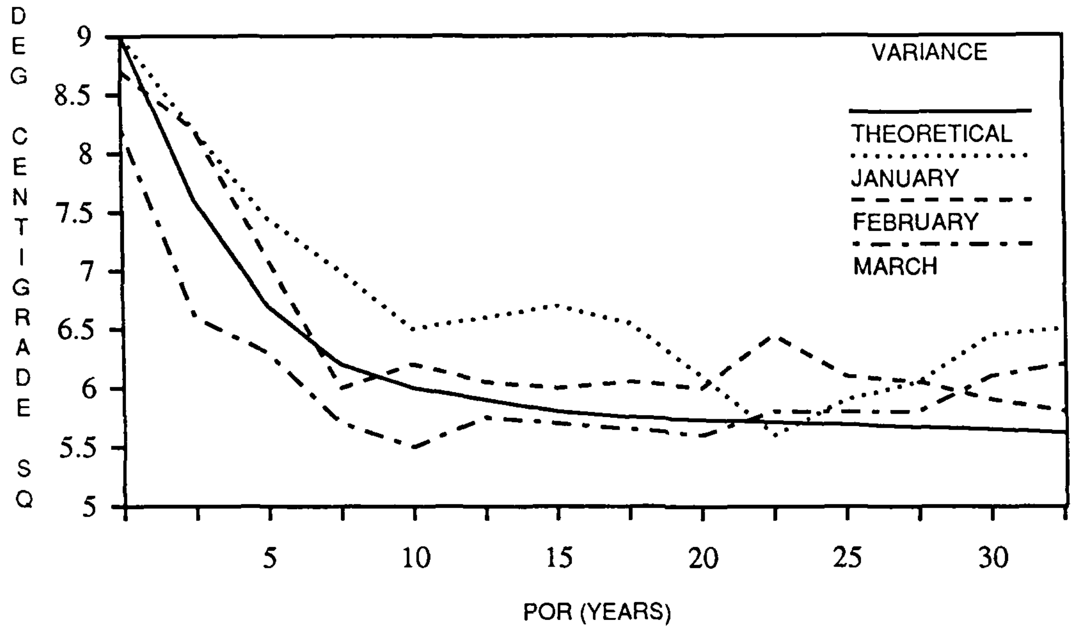

Figure 7. Extrapolation Variance of Temperature (Selected Months) for Lynchburg, Virginia.

3.11 **Best Normals.** Since there are other ways to determine which mean is best (or optimum) for prediction, OL-A opted to look at the area that most frequently approximated what actually happened, much like the approach of Chagnon and Lamb in their work for the Illinois Water Survey Group (Lamb 1980). Working under this premise, OL-A determined that very short PORs were actually better than the 10-15 years of record suggested by Court's work with extrapolation variances. This was an attention -getter for several reasons. For one, climatologists are naturally interested in providing the best climatic data possible with the least expenditure of time and money. For another, the short POR theory would obviously improve confidence in filling requests for climatology on stations with only a few years of weather observation history. To illustrate the "best normal" approach, OL-A prepared a chart of actual vs. predicted ceilings for Ellington AFB, Texas. See Figure 8.

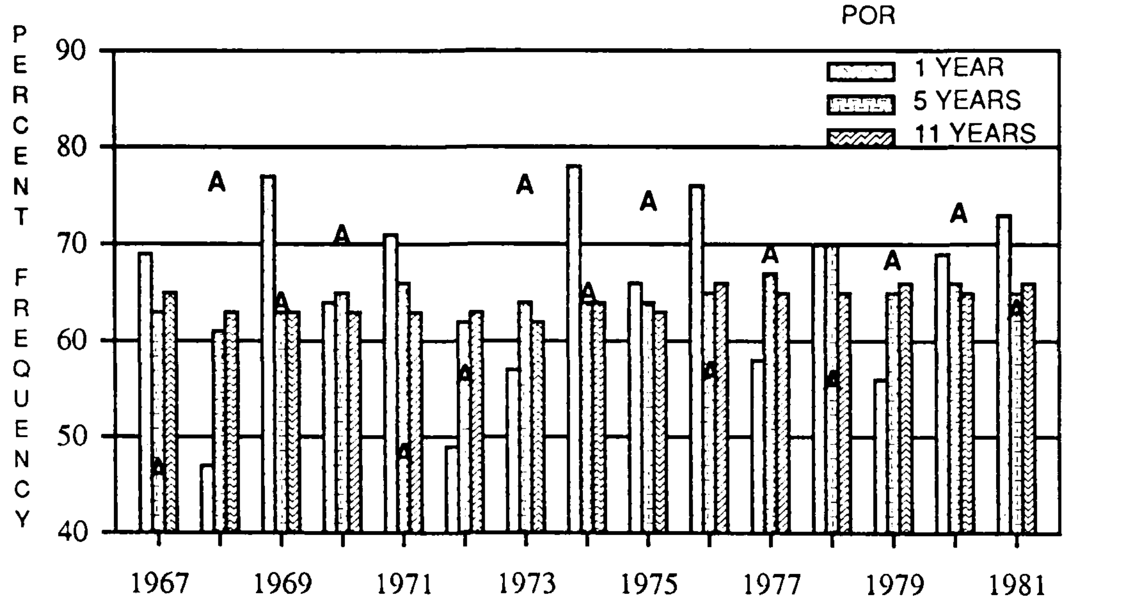

Figure 8. Actual vs. Predicted Percent Frequency, December 500-Ft Ceilings, Ellington AFB, Texas.

3.12 Actual Vs. Predicted Frequencies of 500-Foot Ceilings. Figure 8's bar graphs show the discrete nature of the running means and their performance as predictors. Basic principles still apply--the longest running mean has the least fluctuation. Since the actual values are also plotted (as superimposed "A's"), we can visually evaluate three different predictors. The bar closest to the actual value is the "best predictor," and the mean that is closest most often is the *optimum mean,* or optimum period of record. We are, however, also concerned with the *size* of the prediction error. It may be that a certain mean is frequently the closest predictor but, when evaluated by the size of its error, may, in fact, be the *worst* predictor.

3.13 Seven Means Compared as Predictors. OL-A used seven means at a time in each of its determinations of "best predictor" (Figure 8 was an exception, using only *three* predictors to simplify the example). For ceilings and visibilities, the seven means ranged from 1 to 11 years (the "1-year mean" is a misnomer). Figure 9 shows the results of the seven comparisons for predicting percent frequency of occurrence of January visibilities at Ellington AFB. A tally was scored for the antecedent or predictor mean that was closest to what actually happened. The antecedent "1-year mean, or last year's value, was frequently the closest predictor. Overall, it was the closest predictor most frequently. Since the number of years of quality-assured data was limited, the number of tallies for the month used (January) is not that impressive. There were, however, similar results for all other months and at the other 12 stations used in the study. Figure 10 shows the combined tallies for all 12 months studied at Ellington AFB. Last year's monthly value was again most frequently the closest predictor for this year's actual value. Clearly, the antecedent year was the optimum period of record.

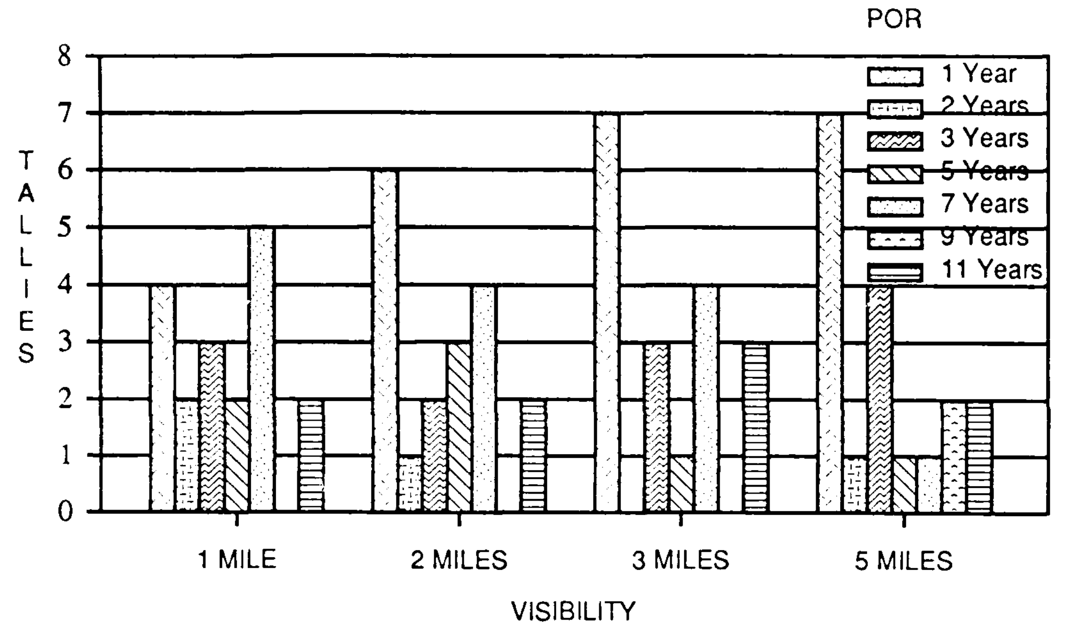

Figure 9. Closest Predictor of Percent Frequency for Selected Visibilities, Ellington AFB, Texas, January, Lag 0.

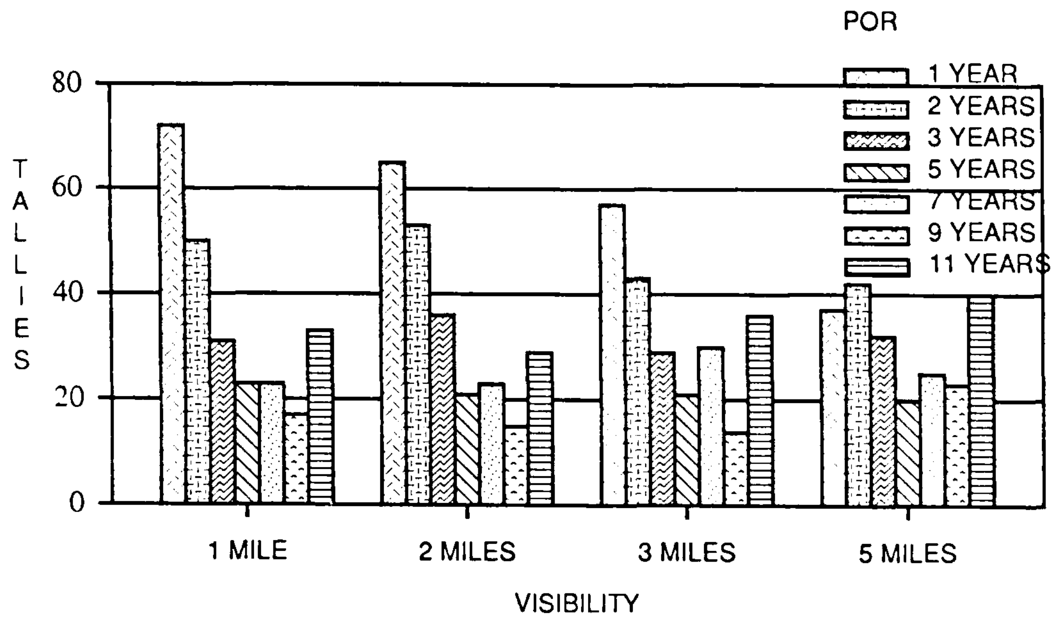

Figure 10. Closest Predictor of Percent Frequency for Selected Visibilities, Ellington AFB, Texas, All Months, Lag 0.

3.14 Predictors for 2, 3, 4, and 5 Years. Since the Standard Summary Package is used for at least 5 years, OL-A looked 2, 3, 4, and 5 years into the future. In other words, there were lags of 1, 2, 3, and 4 years between the last year used in the predictor mean and the year being predicted. Figure 11 shows that the 1-year means were most frequently the closest predictor for all four of the visibility categories for December at Ellington AFB. Other months showed a similar pattern. Figure 12 shows how the antecedent year performs when all the months are grouped together.

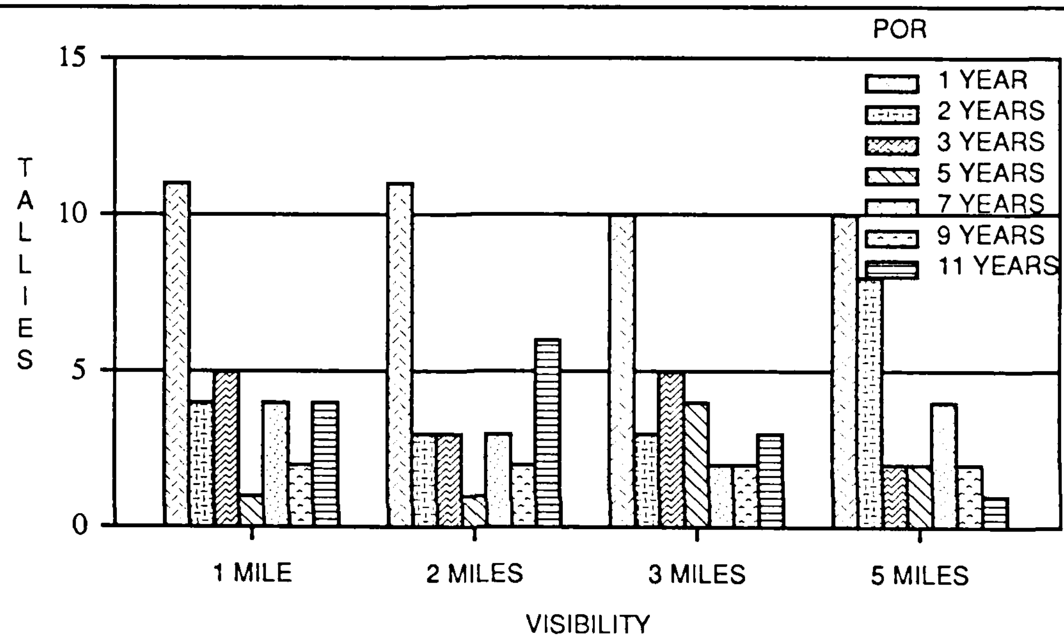

Figure 11. Closest Predictor of Percent Frequency for Selected Visibilities, Ellington AFB, Texas, December, Lag 4.

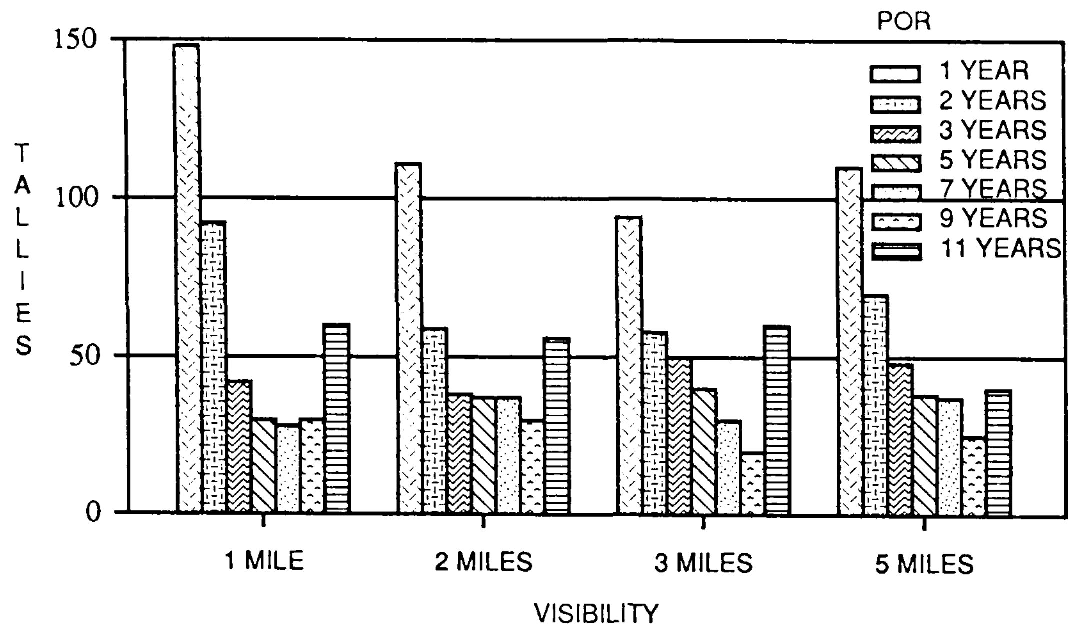

Figure 12. Closest Predictor of Percent Frequency for Selected Visibilities, Ellington AFB, Texas, All Months, Lag 4.

3.15 Last Year's Value May Be Good for 5 Years. The number of tallies for lags of 0 through 4 were plotted to show how well the seven antecedent means performed as predictors for each of the next 5 years. Figure 13 shows how last year's values can be a very good predictor for each of the next 5 years. Although this is just one example and for only 1 month, it was found to be the usual pattern for Scott AFB with visibilities of 5 miles. Figure 14 shows that when all months are combined, the antecedent year's value was frequently the closest to the actual value for each of the next 5 years.

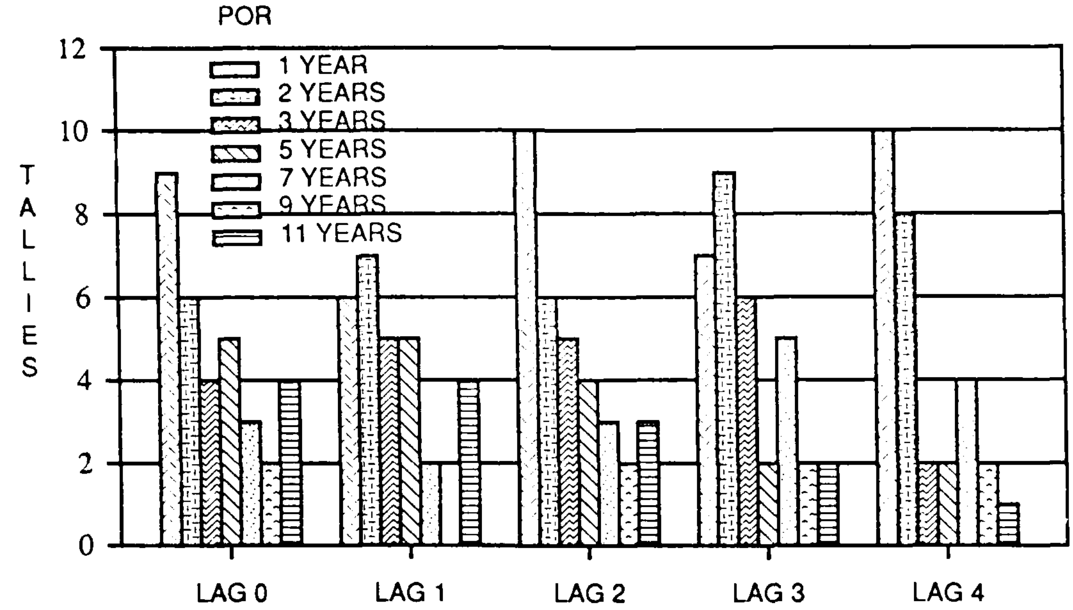

Figure 13. Closest Predictor of Percent Frequency of 5-Mile Visibilities, Scott AFB, Illinois, January, Different Lags.

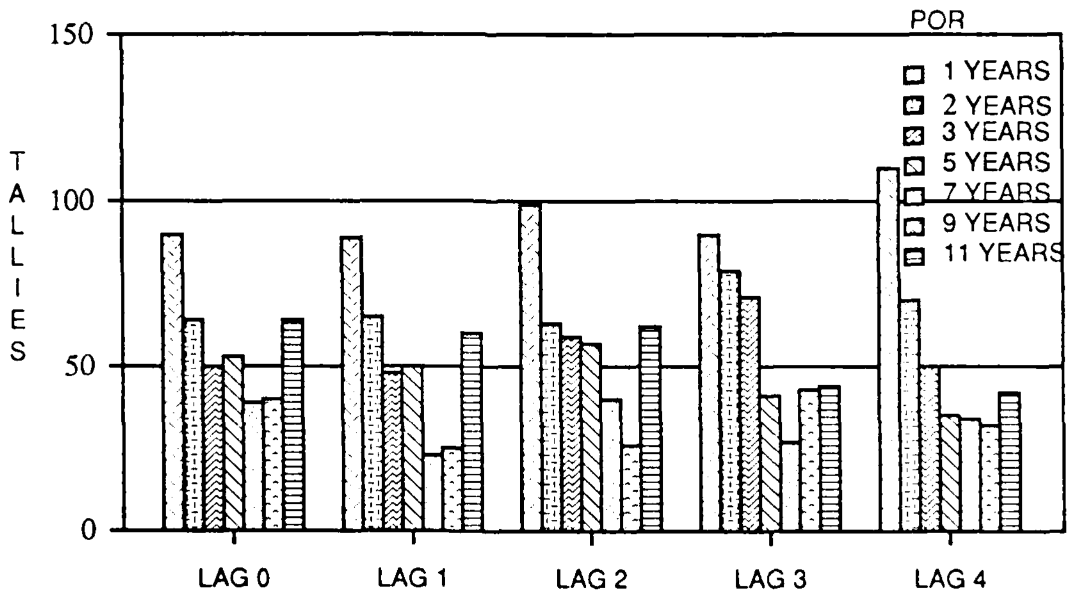

Figure 14. Closest Predictor of Percent Frequency for 5-Mile Visibilities, Scott AFB, Illinois, All Months, Different Lags.

3.16 Antecedent Means as Predictors of Monthly Mean Temperatures. Since there is a longer period of record available for the investigation of temperature means, OL-A was able to use means as long as 31 years. Figure 15 shows that the means for 3 and 5 years perform better as predictors than the longer means for 11, 15, 21, 25, and 31 years. Odd-year means were used to ensure that the medians were actual observed values. Although not presented here as a graphic, the last 6 months were very similar to the first 6 months, and the 3- and 5-year means were the closest predictors most frequently.

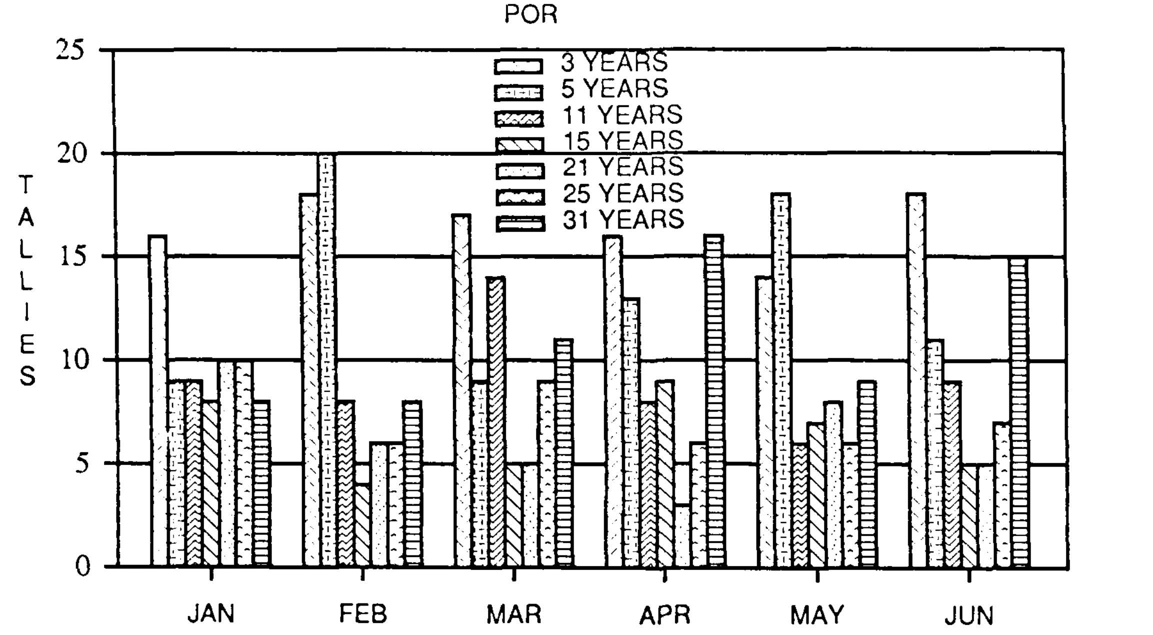

Figure 15. Closest to Actual Mean Temperature, Little Rock, Arkansas, Selected Months.

3.17 Errors of Prediction. The last few figures (and much of the data compiled) prove that short means are frequently the closest predictor of an actual value. However, it was also noted that when the mean was not the closest predictor, it was generally *very* much in error. It's like the "little girl with the curl right in the middle of her forehead." When she (and the short mean) are good, they are "very, very good." But when they are bad, they are horrid. The problem with short means is best illustrated by Figure 7, which shows extrapolation variances for temperature at Lynchburg, Virginia. Arnold Court (1967) did a thorough investigation of this extrapolation variance, and this study by OL-A confirms his results. Figures 16 and 17 show how the extrapolation variance for predictions of frequency of occurrence of ceilings 5,000 feet or greater varies with the size of the antecedent predictor mean. Both figures (along with Figure 7) show that short means have large errors of prediction, both theoretically and empirically.

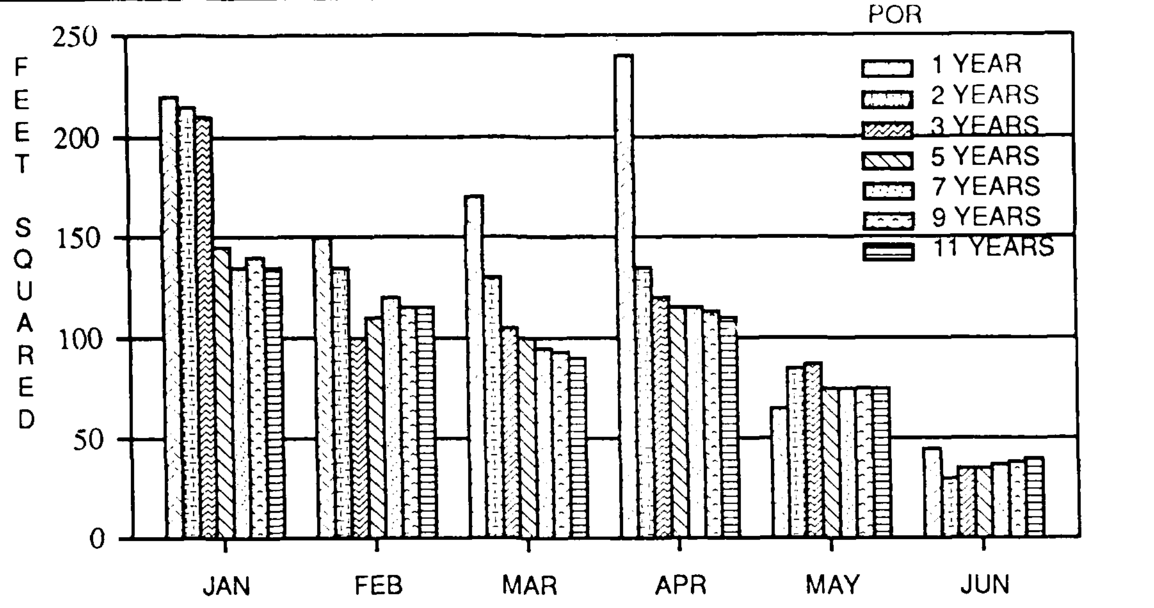

Figure 16. Extrapolation Variances of Ceiling 5,000 Ft or Greater, Ellington AFB, Texas, January-June.

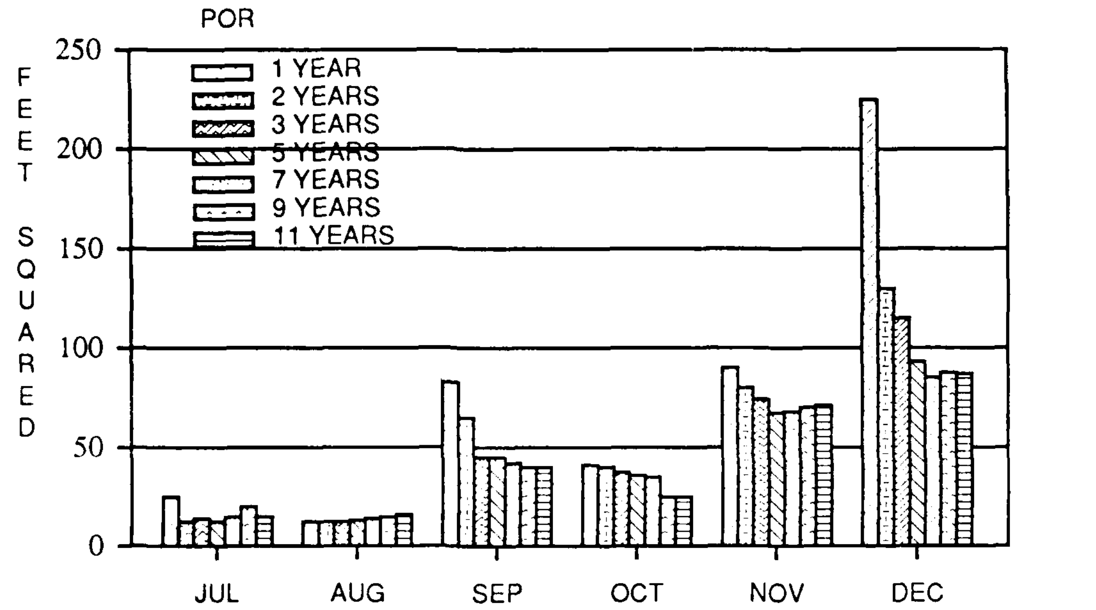

Figure 17. Extrapolation Variances of Ceilings 5,000 Ft or Greater, Ellington AFB, Texas July-December.

3.18 **Frequently the Best, Frequently the Worst.** There are some reservations about the empirical technique of using the mean that is most frequently closest to what actually happens. Clearly, the method developed by Lamb and Chagnon is appropriate for situations in which the *size of* the error is not important. It works well for "win or lose" situations, but if the size of the error is important to the result, this technique should be avoided. Dixon and Shulman (1984) argue that not only do short-term averages produce high frequencies of the "best" (closest predictor), but also high frequencies of the "worst" predictor.

3.19 **Engineering Meteorology Is Different.** The quest for an optimum period of record assumes that means are to be used for current operations or, at most, for just a few years. OL-A was not looking for means in the sense of "normals." For building design and similar purposes, much longer means may be required.

3.20 **Optimum POR Dependent on Criteria.** If the criteria for "best" is to be "closest most often," we can use short POR means. If, on the other hand, we are concerned about the size of the error, we should avoid short POR means like the plague. An intermediate POR, like the 10 years used for the hourly data in USAFETAC's Revised Uniform Summary of Surface Observations (RUSSWO), may be the optimum period of record for a particular station. The results of this study support USAFETAC's policy for summarizing the most recent 10 years of data and providing new summaries every 5 years.

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